Assessing fish habitat supply and potential responses to habitat manipulation in small Canadian Shield lakes

T. Frezza and C.K. Minns

Central and Arctic Region
Department of Fisheries and Oceans, Great Lakes Laboratory for Fisheries and Aquatic Sciences
Burlington, Ontario L7R 4A6

March 2002

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2599

Fisheries and Oceans
Pêches et Océans
Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 901-1425 were issued as Manuscript Reports of the Fisheries Research Board of Canada. Numbers 1426-1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministére des Pêches et des Océans, e'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complèrwa. Le titre exact paraît au-dessus du résumés de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*,et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministére.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et aprés le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur don't le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

102-06358/

Canadian Manuscript Report of

Fisheries and Aquatic Sciences 2599

March 2002

Assessing fish habitat supply and potential responses to habitat manipulation in small Canadian Shield lakes

by

T. Frezza and C.K. Minns

Fisheries and Oceans Canada, Great Lakes Laboratory for Fisheries and Aquatic Sciences, Bayfield Institute, 867 Lakeshore Road, P.O. Box 5050, Burlington, Ontario, L7R 4A6 Canada

© Minister of Supply and Canada 2002

Cat. No. FS97-6/2599 ISSN 0706-6457

Correct citation of this publication:
Frezza, T. and C.K. Minns. 2002. Assessing fish habitat supply and potential responses to habitat manipulation in small Canadian Shield lakes. Can. MS Rep. Fish. Aquat. Sci. 2599: vi+27p.

ABSTRACT

Fish habitat manipulation experiments are under way in three small boreal Shield lakes near Sault Ste. Marie, Ontario. The experiments involve the removal of all woody debris from sections of the littoral zone in each lake and, in one case, the covering of those uncovered littoral substrates with geotextile. To provide a set of *a priori* predictions of expected effects on the fish populations in these lakes, the Defensible Methods (DM) approach of Minns and Nairn (1999) and Minns *et al.* (2001) was applied to estimate the changes in habitat supply as weighted suitable area. The DM approach uses a literature-based assessment of habitat preferences by species and life stage to estimate habitat suitability indices. The habitats were inventoried in each lake and the results mapped using a GIS. Bathymetry, substrate, and cover (vegetation and woody debris) were mapped. Map overlays produced mosaics of polygon each with distinct combinations of depth, substrate, and cover, the key inputs for a DM analysis. The habitat manipulations were represented as additional map overlays. The analyses were conducted in two ways: one using the list of species present in each lake and another using a generic species list representing the species occurring in the tertiary watershed where the lakes are located. The analyses indicated that only minor changes in habitat supply as weighted suitable area were expected to occur as a result of the simulated manipulations. The relative magnitude of response depended on the scale of observation: whole lake, littoral zone, or manipulated areas. Results obtained with lake and watershed species lists were similar. The study led to two conclusions: a) the DM model is poorly suited to small Shield lakes as its method of representing woody debris as cover is rudimentary, but b) nothwithstanding the model limitations, it is important to consider the scale of intervention when designing habitat manipulation experiments. Future research needs stemming from these analyses are suggested.

RÉSUMÉ

Des expériences de modification du relief de l'habitat du poisson sont en cours dans trois petits lacs du bouclier boréal situés près de Sault Ste. Marie, en Ontario. Les expériences comportent l'enlèvement de tous les débris ligneux de certaines parties de la zone littorale de chaque lac et, dans un cas, le recouvrement des substrats exposés de géotextile. Afin d'établir une série de prévisions *a priori* des effets attendus sur les populations de poisson retrouvées dans ces lacs, nous avons fait appel à la démarche des méthodes défendables de Minns et Nairn (1999) et Minns *et al.* (2001) pour estimer les changements dans l'approvisionnement en habitat à titre d'endroit adéquat pondéré. Cette démarche fait appel à une évaluation, reposant sur la documentation, des préférences en matière d'habitat selon l'espèce et le stade du cycle biologique pour estimer les indices de l'adéquation de l'habitat. Nous avons dressé l'inventaire des habitats de chaque lac, puis nous avons utilisé les résultats obtenus pour établir des cartes, à l'aide d'un SIG, de la bathymétrie, du substrat et de la couverture végétale (végétation et débris ligneux). Les transparents superposables que nous avons aussi préparés étaient des mosaïques de polygones, chacune représentant un groupement distinct de profondeur, de substrat et de couverture végétale, soit les principaux intrants d'une analyse par méthodes défendables. Nous avons aussi indiqué les modifications apportées à l'habitat sur des transparents superposables, puis nous avons fait deux analyses différentes : l'une reposant sur la liste des espèces retrouvées dans chaque lac et l'autre, sur une liste générique des espèces retrouvées dans le bassin hydrographique tertiaire où les lacs sont situés. Les analyses ont révélé que seuls des changements mineurs dans l'approvisionnement en habitat à titre d'endroit adéquat pondéré pourraient résulter des modifications du relief simulées. L'ampleur relative de la réaction dépendait de l'échelle des observations, c'est-à-dire si elles portaient sur le lac entier, la zone littorale ou les zones réaménagées. Les deux listes ont donné des résultats semblables. Nous tirons les deux conclusions suivantes : a) le modèle des méthodes défendables se prête mal à l'étude des petits lacs du bouclier boréal du fait qu'il représente mal les débris ligneux comme couverture végétale, et b) indépendamment des limites du modèle, il est important de considérer l'échelle d'intervention au moment de la conception d'expériences de modification du relief de l'habitat. Nous faisons aussi, d'après les résultats de nos analyses, des suggestions pour des recherches futures.

TABLE OF CONTENTS

Abstract iii

Résumé iv

Introduction 1

Methods 2

Study Area 2

Habitat Assessment 2

Habitat Manipulation 3

Fish Habitat Suitability Assessment 3

Results and Discussion 5

Summary 7

References 9

LIST OF TABLES

Table 1 Definition of substrate types revised from Lester *et al.* (1998) 11

Table 2 Definitions and descriptions of macrophyte types (Frezza 2001) 11

Table 3 Habitat cross-matrix linking scenario and database substrate categories by defining scenario substrate types as a percentage 12

Table 4 Habitat cross-matrix linking scenario cover and database vegetation categories by defining scenario cover types 13

Table 5 Species found within each of the study lakes 14

Table 6 Species found within the tertiary watershed of the study lakes 15

Table 7 The minimum and maximum percent change in the WSA after partial wood removal in each lake 17

Table 8 The aggregate weighted suitable area (WSA) results for Quinn Lake habitat manipulations application of the HSM model using lakes species 18

Table 9 The aggregate weighted suitable area (WSA) results for Little Turkey Lake habitat manipulations application of the HSM model using lake species..... 19
Table 10 The weighted suitable area (WSA) results for Little Turkey Lake habitat manipulations application of the HSM model using lake species, partitioned by sub-areas..... 20
Table 11 The weighted suitable area (WSA) results for Quinn Lake habitat manipulations application of the HSM model using lake species, partitioned by sub-areas..... 21
Table 12 The weighted suitable area (WSA) results for Wishart Lake habitat manipulations application of the HSM model using lake species..... 22
Table 13 The weighted suitable area (WSA) results for Wishart Lake habitat manipulations application of the HSM model using tertiary watershed species..... 23
Table 14 Summary of the observed changes (%) in the WSA after partial removal of wood in the lakes..... 24

LIST OF FIGURES

Figure 1 The striped areas around each lake indicate the approximate areas where CWM was removed..... 25
Figure 2 Habitat suitabilities of composite lake species for Little Turkey Lake pre- and post-manipulation..... 26
Figure 3 Cumulative area versus Quinn Lake habitat suitabilities 27

INTRODUCTION

Understanding responses of fish to habitat alterations is important for fish habitat managers especially when making decisions whether to allow developments that would alter potential habitats. Section 35 of the Fisheries Act states 'no person shall carry on any work or undertaking that results in harmful alteration, disruption or destruction of fish habitat'. Canada's Policy for the Management of Fish Habitat (DFO 1986) provides a guiding principle directing implementation of the Fisheries Act of "no net loss of productive capacity of fish habitats". Therefore, to make sound decisions, it is important for habitat managers to anticipate changes to fish populations as a result of habitat alterations.

Direction for managers can be found in scientific literature where studies have investigated fish response to habitat changes. Studies of whole lake manipulations of fish habitat are important to understand the crucial relationships between fish and their habitat (Carpenter *et al.* 1995). However, most studies are carried out at small scales and examine site-specific responses of fish to local habitat changes. Observations of changes to the fish community are made at a site level and it is not known whether the changes are attributed to movement within the lake or a change in the entire population.

Unfortunately, with whole lake experiments, it is difficult to detect changes in fish populations in a short period of time. Annual variability is large, making lengthy studies necessary to detect changes (Lester *et al.* 1996). The issue of time deters implementing long-term studies since it equates to long-term funding and a delay in the acquisition of knowledge (Lester *et al.* 1996). Minns and Nairn (1999) have developed a tool, the Habitat Suitability Matrix (HSM) model, for assessing lacustrine habitat based on equations that measure net change of productivity in fish habitats (Minns 1995 and 1997). Application of the tool is described in Minns *et al* (2001). This tool can be used to predict potential changes in fish habitat suitabilities as a result of habitat alterations, providing insight into the importance of whole lake studies.

In this study we apply the HSM model to assess fish habitat supply and potential responses to habitat manipulations that have been undertaken in three small lakes. Fish habitat within the lakes was manipulated by removing wood cover and, in one lake, adding artificial substrate. It will take time to detect changes in the fish community. Through the application of the HSM model, the assessment of habitat suitability changes allows scientifically-based *a priori* predictions of fish community changes. We also

used the HSM model to determine potential habitat suitability changes as a result of proposed manipulations of full wood removal within the lakes.

METHODS

Study Area

Three small (<0.25 km^2) Canadian Shield lakes were used for this analysis. Wishart Lake and Little Turkey Lake are located within the Turkey Lakes Watershed (84°25'W, 47°03'N), and Quinn Lake (84°13'14"W, 46°43'52"N) is located north of Sault Ste. Marie (Figure 1).

Habitat Assessment

Maps of the spatial distribution of substrate, macrophyte, and wood coverage were completed on all three lakes using the littoral zone cruise habitat assessment method (Frezza 2001) within the littoral zone area (area between shore and the 2 m depth contour). All field sampling on the lakes took place between July 1 and September 5, 1998. Substrate was classified into eight different habitat types by particle size (Table 1) and macrophytes into seven categories according to growth forms (Table 2). Pieces of coarse woody material (CWM) (greater than 10 cm diameter) were counted in approximately every 20-50 m of shoreline distance from shore to the 2 m contour. Using a GIS, the shoreline of each lake was divided into sections where the wood was counted, and the corresponding wood count assigned to each section. From a previous habitat assessment completed on these study lakes using a transect sampling method (Frezza 2001), the average distance from shore that wood was present was calculated. A buffer zone, using the average distance wood was found from shore as its width, was placed parallel to the shoreline segments to create polygons. The density of wood within each polygon was calculated (number of pieces of wood per $metre^2$ of shoreline). Wood densities within polygons were grouped into five classes: 0 pieces/m^2; 0.01-0.5 pieces/m^2; 0.51-1.5 pieces/m^2; 1.51-2.5 pieces/m^2; and >2.5 pieces/m^2. The macrophyte and wood distribution maps were overlaid to create a distribution of cover with unique polygons of macrophyte and wood density combinations. For example a classification of 0.5/ Carpet is interpreted as the polygon having a CWM density class of 0.5 pieces of wood/m^2 and the macrophyte type 'carpet'.

Bathymetric maps of the lakes were classified into depth categories. The nearshore areas were classified into two classes (0-1 m and 1-2 m) depth and the offshore into three classes (2-5 m, 5-10 m, and >10 m depth). Ontario Ministry of Natural

Resource (OMNR) staff performed the bathymetric surveys and provided digital georeferenced data. In the offshore area, considered a mud zone, substrates were assumed to be uniformly a 50:50 mix of silt and clay.

Maps of each of the habitat distribution maps (substrate and cover) for each lake were overlaid with a bathymetric map. The resulting habitat map of each lake consisted of unique homogeneous polygons with an attribute for depth, substrate, and cover (both macrophyte and wood). Since the macrophyte areas were delimited, homogeneous polygons containing macrophytes were assumed to have 100 percent cover. Each polygon was assigned a unique identifier and its area calculated.

Habitat Manipulation

All three lakes previously had their inlake fish habitat manipulated (Wishart and Quinn Lakes in 1999 and Little Turkey Lake in 2000). All CWM creating vertical structure was removed from the littoral zone along 50% of the shoreline to a depth of 2 m or 10 m from shore (whichever came first) on all three lakes (Figure 1) (Smokorowski, personal communication). In Little Turkey Lake, in addition to the wood removal, two areas of the littoral zone substrate were covered with a geotextile material. One area of substrate that was covered stretched 100 m along the shoreline and extended 3 m from shore. The other area stretched 200 m along the shoreline and 3 m from shore (Figure 1) (Smokorowski, personal communication).

Scenarios were created of the post-manipulation habitat distributions using a GIS. Areas that were manipulated were identified on the habitat maps (depth, substrate, and cover) of each lake. The wood density component of the cover attribute for each polygon in the manipulated areas was changed to 0 pieces of wood/m^2. The substrate in the areas of Little Turkey Lake that were covered by geotextile were classified as bedrock as this is a substrate type impermeable to fish and provides no cover within interstitial spaces. A mock scenario was also created for each of the lakes where all wood densities within the lakes were changed to 0 pieces of wood/m^2, imitating full wood removal.

Fish Habitat Suitability Assessment

Pre-manipulation and post-manipulation habitat suitabilities and weighted suitable areas (WSA; area multiplied by suitability) were calculated for each of the lakes using the scientifically defensible Habitat Suitability Matrix (HSM) model software described by Minns and Nairn (1999) and Minns *et al* (2001). This software calculates habitat suitabilities at three life stages of fish, young-of-the-year, spawning, and adult, using

literature-based databases assembled by Lane *et al.* (1996 a,b,c). The weights assigned to the life stages were equal for all of the analyses.

The habitat categories assigned to each unique polygon were different than those provided in the HSM model software. We specified habitat cross-matrices linking the habitat categories from the pre- and post-manipulation scenarios and database habitat categories. Substrate and cover types were described by percentages of the habitat categories included in the HSM (Tables 3 and 4). For example, the substrate categories in the scenarios consisted of combinations of habitat types from Table 1 such as a 'boulder/gravel' combination. A link to the database categories was done by describing 'boulder/gravel' as 50% boulder and 50% gravel. The cover categories used for the scenario included both a CWM density and a macrophyte type whereas the HSM habitat categories do not include wood coverage. Limitations in the input databases of HSM mean that non-vegetation cover categories are not represented. To incorporate wood coverage into the analyses, different densities of wood were described as percentages of submergent vegetation. The denser the wood coverage, a higher percentage of submergent vegetation was assigned (Table 4). The macrophyte component of the cover categories was also very different from the HSM vegetation categories. We estimated the percentage of each macrophyte category from Table 2 that is considered submergent, emergent, or no cover (HSM vegetation categories) (Table 4).

Habitat suitabilities for the unique polygons were estimated using species found within each lake (Table 5) as well as species in the tertiary watershed (Table 6). Whether using the lake or watershed species list, the species were grouped by thermal (cold, cool, warm) and trophic (piscivore, non-piscivore) characteristics. Each species within one of the six groups was given equal weight. For suitability indices pooled across the six groups, each fish group was given equal weight in a weighted mean suitability. Since the number of species in each thermal-trophic group varies, the two stages of pooling do not produce simple arithmetic mean results in WSA.

To further clarify the results from the fish habitat suitability assessments completed on the entire lakes, the habitat cover maps were subdivided into sections. Each area that was manipulated was isolated into a separate scenario for both pre- and post-manipulations. The offshore area (>2 m depth) and the nearshore area (excluding manipulated areas) were also isolated into separate scenarios. This enabled an examination of the change in habitat suitabilities for the manipulated areas only, while still being able to look at the whole lake effect of the manipulations.

The cumulative area of polygons was plotted against the habitat suitabilities for both the pre- and post-manipulation analyses. This provides a visual assessment of how the habitat suitabilities of the manipulated areas change with respect to the original habitat distribution.

The habitat suitabilities for each polygon, both pre- and post-manipulation were linked back to the original habitat maps using the unique identifiers. Maps of habitat suitabilities were created for each lake (Figure 2).

RESULTS AND DISCUSSION

Removing partial wood coverage in the lakes did not have a large effect on the weighted suitable areas (WSA) for any of the life stages or species groups. In all lakes, the area of habitat affected was small compared to the total area of the littoral zone or the whole lake. In some cases, there was an increase in the WSA after the removal of wood. The ranges in the percent changes of the WSA's after habitat manipulations for each are found in Table 7. Overall, Quinn Lake had the greatest loss of WSA of approximately 23% and the greatest gain in WSA of almost 10% using lake species in the analysis. For pooled species and overall, there were not great changes in the WSA (-5.3 to +6.0 %). Certain species groups were affected more than others (-23.1 to +9.8 %). When the species were pooled together, these differences balanced out. For example, in Quinn Lake, the percent change of WSA for adult coldwater non-piscivores was –23.1% with partial wood removal (Table 8). When the adult groups were pooled, there was no change in the WSA (Table 8) because the offshore component of WSA for adult piscivores was much larger.

Within Little Turkey Lake, both substrate and wood cover were manipulated. Neither of the manipulations greatly changed the amount of suitable area available in the whole lake (Table 9). The manipulated areas were small compared to total lake area as only approximately 0.42% of the whole lake and approximately 1.8% of the littoral zone was covered with geotextile. When the scale of observation is changed from the whole lake to the areas that were manipulated, in all but four cases, the change in WSA was a loss of 100% for species groups in each life stage (Table 10). This change in WSA can be visibly seen in Figure 2. Thus the scale of impacts depends on the reference scale. Despite the substrate change and the wood removal, Figure 2 shows that habitat suitability in the area with the geotextile remained low. With full wood removal in that area, but no change in substrate, the suitability is higher than with the geotextile. The

artificial substrate was classified as bedrock since both substrates were considered to be smooth and impermeable. As resuspended sediment and detritus accumulates on the geotextile, its apparent substrate equivalency may change. Most species occur in association with a variety of substrates although few fishes use bedrock as nursery, spawning, or adult habitat (Lane *et al.* 1996 a,b,c). Burbot (*Lota lota*), a coldwater piscivore, has a high association with bedrock for adult use (Lane *et al.* 1996b), as well as lake trout (*Salvelinus namaycush*; coldwater piscivore) which uses bedrock for spawning (Lane *et al.* 1996c). Coldwater piscivores are the only species group that did not have a 100% reduction in WSA after the geotextile was added.

A change in the scale of observation for the partial wood removal also shows how the immediate area manipulated differs from the whole lake. In Quinn Lake there was both an increase and decrease in the WSA after wood removal. Coolwater non-piscivores in adult and spawning life stages had decreases in WSA of 23% and 15% respectively for the whole lake (Table 8). In the areas that were manipulated, there were greater decreases in WSA for that species group (Table 11). Similarly, coldwater piscivores, the other species group in Quinn Lake, had increases in WSA. In one area that was manipulated, there was a 50% loss of WSA for coolwater non-piscivores, but a 50% increase for coldwater piscivores (Table 11). The effect of wood removal was not consistent between the species groups. Brook trout (*Salvelinus fontinalis*), the coldwater piscivore in Quinn Lake, was assumed to use rubble and gravel for spawning, adult and nursery grounds with no association with submergent vegetation (Lane et al 1996 a,b,c). Using Biro and Ridgway's (1995) observations of brook trout yoy orientation to submerged objects as a basis for the suitability model would alter the outcome somewhat. By removing the wood cover in those areas with rubble and gravel, the WSA increases as more area becomes available to brook trout. Northern redbelly dace (*Phoxinus eos*) and golden shiner (*Notemigonus crysoleucas*), both coolwater non-piscivores, have high associations with submergent vegetation. Since wood cover was equated to submergent vegetation, this would be a loss in suitable areas for these species.

Tertiary watershed species were included in the analyses to account for potential use of habitat within the lakes. For Wishart Lake there were three species groups within the lake (Table 5) while in the TWS, there are six species groups (Table 6). The results between the two species lists were similar (Tables 12 and 13). The WSA changed

slightly for some groups since more species were considered in the creation of the suitability matrices.

As an extension to the habitat manipulation, there is a proposal to remove all the wood from one of the lakes to observe the effects on the fish community (John Kelso, personal communication). Wood is an integral part of the littoral zone, with residence times as long as ten centuries (Guyette and Cole 1999). It provides physical structure, creating cover and shading for fish, and refuge from predation (Everett and Ruiz 1993; Biro and Ridgway 1995). Because of the role wood plays, we expected a large decrease in habitat suitabilities with our mock scenarios of wood removal. However, as demonstrated above, some species do not have an association with submergent vegetation and prefer open gravel and rubble areas. By removing the wood, there were more suitable areas provided for those species (Figure 3). Alternately, those species with high associations with submergent vegetation showed a decrease in the amount of suitable habitat (Figure 3). This kind of detailed consideration shows the current limitation of the HSM model as woody debris as cover is not explicitly represented in the model. Quinn Lake had the greatest loss of suitable area from full wood removal for lake species in the coolwater non-piscivore group (-42%; Table 8) but overall there was an increase in WSA. Table 14 summarizes the directional changes (increase or decrease) in the WSA for each species group predicted in response to the partial removal of wood in the littoral zone of each lake. For the majority of species groups the change in the WSA was consistent for all of the lakes. Furthermore, in most cases, the WSA of similar thermal groups had the same directional change. Minns *et al.* (1999) found that composite suitability indices were sensitive to changes in thermal weights with the greatest differences in habitat suitabilities between warmwater and coldwater species while life stage and trophic differences were much less.

SUMMARY

Given the documented importance of wood in the littoral zone (Everett and Ruiz 1993; Christensen *et al.* 1996; Bowen *et al.* 1998; Guyette and Cole 1999; Mallory *et al.* 2000), we expected wood removal to significantly decrease the amount of suitable habitat for fish species. The amount of suitable area did decrease for some species, but for others there was an increase. This may be due in part to the way wood was represented in our analyses. We did not have a complete areal distribution of wood coverage, therefore we used approximate areas where wood might be found. Also, we

may have tested the limits of the Habitat Suitability Matrix model as wood coverage is not incorporated into the habitat databases. We defined wood cover being equivalent to submergent vegetation and assumed that fish species associations with submergent vegetation are equivalent to their association with wood coverage.

Despite the limitations of the HSM model in representing wood cover, changes to a particular habitat type, whether it be wood or substrate, will change the amount of suitable habitat for each species differently. Scale of observation is an important issue. While differences between pre- and post-manipulation of woody debris habitat may be detected for certain species, changes at the community level may be difficult to detect.

The scale of manipulation was also an issue with the addition of artificial substrate. There was such a small area within Little Turkey Lake that was manipulated that the effect of the manipulation was negligiable at the whole lake level. If no change in the fish community is observed as a result of this substrate manipulation, it cannot be determined whether it is due to weaker associations between fish and habitats than expected or the failure to make a significant change in the available habitat.

Overall the results obtained from this application of the HSM model in these small Shield lakes subject to habitat manipulation point to two key conclusions:

1) The HSM model has limitations in Shield lakes where woody debris is perceived to be a major component of fish habitat cover in the littoral zone. Observations on woody debris habitat preferences are limited in the literature making it difficult to adequately represent it in HSM analyses. Further, using vegetation cover as a proxy for woody debris cover has limitations because of underlying connections with substrate and depth range preferences. Additional knowledge of cover preferences is needed for a wider range of species occurring in Ontario lakes and the HSM model needs to be extended to consider woody debris explicitly.
2) Notwithstanding the limitations of the HSM model, this series of analyses highlights the importance of considering scale when designing habitat manipulation experiments. Unlike chemical experimentation in lakes where changes in nutrient or pH levels are pervasive, physical habitat manipulations are spatially limited. At both the whole lake and littoral zone scales, the actual manipulated areas were very small. The analyses assumed that all areas contribute to habitat supply for the fish presence. Hence a very large area in the offshore with a low suitability value can outweigh a small littoral area with a high suitability value. It is generally understood that habitat utilization by fish does not occur strictly according to an ideal-free

distribution model. However, until there is better quantification of habitat use by fish for production support for null hypotheses of no effect for habitat manipulations in lakes will tend to result from this kind of habitat-based *a priori* analysis. Greater emphasis on measuring the relative contribution of particular habitats to total lake production in species populations of fish and identifying ontological bottlenecks in habitat supply is needed to overcome these problems.

REFERENCES

Biro, P.A. and M.S. Ridgway. 1995. Individual variation in foraging movements in a lake population of young-of-year brook charr (*Salvelinus fontinalis*). Behaviour. 132:57-74.

Bowen, K.L., N.L. Kauskik, and A.M. Gordon. 1998. Macroinvertebrate communities and biofilm chlorophyll on submerged woody debris in two Canadian oligotrophic lakes. Archiv fur Hydrobiologie. 141:257-281.

Carpenter, S.R., P. Cunningham, S. Gafny, A. Muñoz-Del-Rio, N. Nibbelink, M. Olson, T. Pellett, C. Storlie, and A. Trebitz. 1995. Responses of bluegill to habitat manipulations: Power to detect effects. North American Journal of Fisheries Management. 15(3):519-527.

Christensen, D.L., B.R. Herwig, D.E. Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications. 6(4):1143-1149.

DFO. 1986. Policy for the Management of Fish Habitat. Department of Fisheries and Oceans, Ottawa, Ontario. 30p.

Everett, R.A. and G.M. Ruiz. 1993. Coarse woody debris as a refuge from predation in aquatic communities: an experimental test. Oecologia. 93:475-486.

Frezza, T.L. 2001. A comparison of observer repeatability and precision of sampling using two different fish habitat assessment methods in lakes: transect sampling and the littoral zone cruise. Master's thesis. Trent University.

Guyette, R.P. and W.G. Cole. 1999. Age characteristics of coarse woody debris (*Pinus strobus*) in a lake littoral zone. Canadian Journal of Fisheries and Aquatic Sciences. 56:496-505.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996a. Nursery habitat characteristics of Great Lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2338:42p.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996b. Adult habitat characteristics of Great Lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2358:43p.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996c. Spawning habitat characteristics of Great Lakes fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2368:48p.

Lester, N.P., W.I. Dunlop, and C.C. Willox. 1996. Detecting changes in the nearshore fish community. Canadian Journal of Fisheries and Aquatic Sciences. 53 (Suppl.1):391-402.

Mallory, E.C., M.S. Ridgway, A.M. Gordon, and N.K. Kaushik. 2000. Distribution of woody debris in a small headwater lake, Central Ontario, Canada. Archiv fur Hydrobiologie. 148(4):587-606.

Minns, C.K. 1995. Calculating net change of productivity of fish habitats. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2282:vi+37p.

Minns, C.K. 1997. Quantifying 'no net loss' of productivity of fish habitats. Canadian Journal of Fisheries and Aquatic Sciences. 54:2463-2473.

Minns, C.K., and R.B. Nairn. 1999. Defensible methods: Applications of a procedure for assessing developments affecting littoral fish habitat on the Lower Great Lakes. *In:* Aquatic Restoration in Canada. *Editors:* T. Murphy and M.Munawar. Ecovision World Monograph Series. Backhuys Publishers, Leiden, The Netherlands. pp. 15-35.

Minns, C.K., J.E. Moore, M. Stoneman, and B. Cudmore-Vokey. 2001. Defensible Methods of Assessing Fish Habitat: Lacustrine Habitats in the Great Lakes Basin – Conceptual Basis and Approach Using a Habitat Suitability Matrix (HSM) Method. Can. MS Rpt. Fish. Aquat. Sci.2559:viii+70p.

Minns, C.K., P.M. Brunette, M. Stoneman, K. Sherman, R. Craig, C. Portt, and R.G. Randall. 1999. Development of a Fish Habitat Classification Model for Littoral Area of Severn Sound, Georgian Bay, a Great Lakes' Area of Concern. Canadian Manuscript Report for Fisheries and Aquatic Sciences. 2490:ix+86p.

Table 1. Definition of substrate types revised from Lester *et al.* (1998).

Substrate types	Definition
Bedrock	Exposed rock, no overburden
Boulder	>25 cm
Rubble	8 - 25 cm
Gravel	0.2 - 8 cm
Sand	<0.2 cm
Silt/Muck/Detritus	Inorganic, soft and decaying organic
Clay	Inorganic without structure
Other	Does not fit into any of the other categories

Table 2. Definitions and descriptions of macrophyte types (Frezza 2001).

Macrophytes	Description
Grass-like	Tall thin plants, slender leaves, no lateral foliage
Carpet	Creating bottom cover
Cover rooted	Providing surface cover, rooted
Cover, no roots	Providing surface cover, not rooted
Leafy, extending to surface of water	Leafy foliage, extending vertically to the water's surface
Leafy, extending no further than half way through water column	Leafy foliage, extending vertically only half way up the water column

Table 3. Habitat cross-matrix linking scenario and database substrate categories by defining scenario substrate types as a percentages database substrate categories. HSM substrate categories are in the columns and scenario substrate categories are in the rows.

	Bedrock	Boulder	Cobble	Rubble	Gravel	Sand	Silt	Clay	Hardpan	Pelagic	Unused
Bedrock	1										
Boulder		1									
Rubble				1							
Gravel					1						
Sand						1					
Muck							1				
Clay								1			
Other											1
Boulder/ Rubble		0.5		0.5							
Boulder/ Gravel		0.5			0.5						
Boulder/ Muck		0.5					0.5				
Mudzone 2-5 m							0.5	0.5			
Mudzone 5-10 m							0.25	0.25		0.5	
Mudzone >10 m							0.1	0.1		0.8	

Table 4. Habitat cross-matrix linking scenario cover and database vegetation categories by defining scenario cover types as percentages of database vegetation categories. HSM vegetation categories are in the columns and scenario cover categories are in the rows. The number in the cover categories indicates the wood density class.

	Submergent	Emergent	No Cover
0/ Bare			1
0/ Grass-like		0.75	0.25
0/ Carpet	0.2		0.8
0/ Cover rooted	0.5		0.5
0/ Leafy to surface	0.75		0.25
0/ Leafy half way to surface	0.5		0.5
0.5/ Bare	0.1		0.9
0.5/ Grass-like	0.1	0.75	0.15
0.5/ Carpet	0.3		0.7
0.5/ Cover rooted	0.6		0.4
0.5/ Leafy to surface	0.85		0.15
0.5/ Leafy half way to surface	0.6		0.4
1.5/ Bare	0.2		0.8
1.5/ Grass-like	0.2	0.75	0.05
1.5/ Carpet	0.4		0.6
1.5/ Cover rooted	0.7		0.3
1.5/ Leafy to surface	0.95		0.05
1.5/ Leafy half way to surface	0.8		0.2
2.5/ Bare	0.3		0.7
2.5/ Grass-like	0.3		0.7
2.5/ Carpet	0.5		0.5
2.5/ Cover rooted	0.8		0.2
2.5/ Leafy to surface	1		
2.5/ Leafy half way to surface	0.8		0.2
3/ Bare	0.4		0.6
3/ Grass-like	0.4	0.6	
3/ Carpet	0.6		0.4
3/ Cover rooted	0.9		0.1
3/ Leafy to surface	1		
3/ Leafy half way to surface	0.9		0.1

Table 5. Species found within each of the study lakes. Grouping of species is done by trophic level and thermal preference.

Lake		Common name	Scientific name
Little Turkey	Coldwater piscivores	Brook trout	*Salvelinus fontinalis*
		Lake trout	*Salvelinus namaycush*
		Burbot	*Lota lota*
	Coolwater non-piscivores	Northern redbelly dace	*Phoxinus eos*
		Common white sucker	*Catostomus commersoni*
		Log perch	*Percina caprodes*
		Lake chub	*Couesius plumbeus*
		Golden shiner	*Notemigonus crysoleucas*
		Ninespine stickleback	*Pungitius pungitius*
		Emerald shiner	*Notropis atherinoides*
	Warmwater non-piscivores	Bluntnose minnow	*Pimephales notatus*
		Fathead minnow	*Pimephales promelas*
Quinn	Coldwater piscivore	Brook trout	*Salvelinus fontinalis*
	Coolwater non-piscivores	Northern redbelly dace	*Phoxinus eos*
		Golden shiner	*Notemigonus crysoleucas*
Wishart	Coldwater piscivores	Brook trout	*Salvelinus fontinalis*
		Burbot	*Lota lota*
	Coolwater non-piscivores	Common white sucker	*Catostomus commersoni*
		Northern redbelly dace	*Phoxinus eos*
		Lake chub	*Couesius plumbeus*
		Emerald shiner	*Notropis atherinoides*
	Warmwater non-piscivores	Bluntnose minnow	*Pimephales notatus*
		Fathead minnow	*Pimephales promelas*

Table 6. Species found within the tertiary watershed of the study lakes. Groupings are based on thermal preference and trophic level.

Group	Common Name	Scientific Name
Coldwater non-piscivores	Sea lamprey	*Petromyzon marinus*
	Lake sturgeon	*Acipenser fulvescens*
	Lake whitefish	*Coregonus clupeaformis*
	Cisco	*Coregonus artedii*
	Bloater	*Coregonus hoyi*
	Kiyi	*Coregonus kiyi*
	Shortnose cisco	*Coregonus reighardi*
	Shortjaw cisco	*Coregonus zenithicus*
	Round whitefish	*Prosopium cylindraceum*
	Longnose sucker	*Catostomus catostomus*
	Pearl dace	*Margariscus margarita*
	Trout-perch	*Percopsis omiscomaycus*
	Mottled sculpin	*Cottus bairdi*
	Slimy sculpin	*Cottus cognatus*
Coldwater piscivores	Coho salmon	*Oncorhynchus kisutch*
	Chinook salmon	*Oncorhynchus tshawytsch*
	Rainbow trout	*Oncorhynchus mykiss*
	Brown trout	*Salmo trutta*
	Brook trout	*Salvelinus fontinalis*
	Lake trout	*Salvelinus namaycush*
	Burbot	*Lota lota*
Coolwater non-piscivores	American brook lamprey	*Lampetra appendix*
	Silver lamprey	*Ichthyomyzon unicuspis*
	Rainbow smelt	*Osmerus mordax*
	White sucker	*Catostomus commersoni*
	Silver redhorse	*Moxostoma anisurum*
	Shorthead redhorse	*Moxostoma macrolepidotum*
	Northern redbelly dace	*Phoxinus eos*
	Finescale dace	*Phoxinus neogaeus*
	Lake chub	*Couesius plumbeus*

	Brassy minnow	*Hybognathus hankinsoni*
	Golden shiner	*Notemigonus crysoleucas*
	Emerald shiner	*Notropis atherinoides*
	Common shiner	*Luxilus cornutus*
	Blackchin shiner	*Notropis heterodon*
	Blacknose shiner	*Notropis heterolepis*
	Spottail shiner	*Notropis hudsonius*
	Blacknose dace	*Rhinichthys atratulus*
	Longnose dace	*Rhinichthys cataractae*
	Creek chub	*Semotilus atromaculatus*
	Fallfish	*Semotilus corporalis*
	Banded killifish	*Fundulus diaphanus*
	Brook stickleback	*Culaea inconstans*
	Ninespine sticleback	*Pungitius pungitius*
	Yellow perch	*Perca flavescens*
	Iowa darter	*Etheostoma exile*
	Johnny darter	*Etheostoma nigrum*
	Logperch	*Percina caprodes*
Coolwater piscivores	Northern pike	*Esox lucius*
	Walleye	*Stizostedion vitreum vitreum*
Warmwater non-piscivores	Gizzard shad	*Dorosoma cepedianum*
	Central mudminnow	*Umbra limi*
	Rosyface shiner	*Notropis rubellus*
	Sand shiner	*Notropis stramineus*
	Mimic shiner	*Notropis volucellus*
	Bluntnose minnow	*Pimephales notatus*
	Fathead minnow	*Pimephales promelas*
	Brown bullhead	*Ameiurus mebulosus*
	Rock bass	*Ambloplites rupestris*
	Pumpkinseed	*Lepomis gibbosus*
	Bluegill	*Lepomis macrochirus*
Warmwater piscivores	Smallmouth bass	*Micropterus dolomieui*
	Largemouth bass	*Micropterus salmoides*

Table 7. The minimum and maximum percent change in the WSA after partial wood removal in each lake for *pooled lakes species*, *lakes species*, *pooled tertiary watershed* (TWS) species and TWS species.

Species list	Lake	Minimum WSA	Maximum WSA
Pooled lake species	Little Turkey	-1.95	-0.76
	Wishart	-0.39	0.63
	Quinn	-5.31	6.04
Lake species	Little Turkey	-22.25	1.41
	Wishart	-7.79	1.56
	Quinn	-23.10	9.76
TWS pooled species	Little Turkey	-1.27	1.04
	Wishart	-0.9	0.82
	Quinn	-5.49	-2.39
TWS species	Little Turkey	-10.96	1.30
	Wishart	-2.32	1.98
	Quinn	-22.34	7.78

Table 8. The aggregate weighted suitable area (WSA) results for Quinn Lake habitat manipulations application of the HSM model using lakes species. Shown is the pre- and post-manipulation (partial and full wood removal), net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, P= piscivore, NP= non-piscivore

Type	Group	Pre	Post- partial wood	Post- full wood	Net Change- partial wood	Net Change- full wood	% (partial)	% (full)
Adult	CLDW-P	31002.4	32421.2	33567.1	1418.8	2564.7	4.6	8.3
	CW-NP	6075.1	4671.7	3546.8	-1403.4	-2528.3	-23.1	-41.6
Spawning	CLDW-P	5040.7	5532.6	5947.8	491.9	907.1	9.8	18.0
	CW-NP	7799.5	6625.7	5679.1	-1173.8	-2120.4	-15.0	-27.2
YOY	CLDW-P	17253.6	18212.7	18997.8	959.1	1744.2	5.6	10.1
	CW-NP	16039.7	17091	17923.2	1051.3	1883.5	6.6	11.7
Pooled:								
Adult	Adult	18538.8	18546.5	18556.9	7.7	18.1	0.0	0.1
Spawning	Spawning	6420.1	6079.2	5813.4	-340.9	-606.7	-5.3	-9.4
YOY	YOY	16646.6	17651.9	18460.5	1005.3	1813.9	6.0	10.9
OverAll Sum		13868.5	14092.5	14277	224	408.5	1.6	2.9

Table 9. The aggregate weighted suitable area (WSA) results for Little Turkey Lake habitat manipulations application of the HSM model using lakes species. Shown is the pre- and post-manipulation (substrate only, wood and substrate, and full wood removal), net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Type	Group	Pre	Post-wood and substrate	Post-substrate only	Post- full wood removal	Net Change-wood and substrate	Net Change-substrate	Net Change (full removal)	% (wood and substrate)	% (substrate only)	% (Full removal)
Adult	CLDW-P	99752.4	99790.5	99662.3	100048.7	38.1	-90.1	296.3	0.0	-0.1	0.3
	CW-NP	91575.5	90982.1	91168.2	91019.6	-593.4	-407.3	-555.9	-0.7	-0.4	-0.6
	WW-NP	4202.9	3267.6	3894.7	2754.1	-935.3	-308.2	-1448.8	-22.3	-7.3	-34.5
Spawning	CW-P	23467.8	23799.8	23224.8	24593.9	332	-243	1126.1	1.4	-1.0	4.8
	CW-NP	20930.8	20434.1	20369.6	20948.1	-496.7	-561.2	17.3	-2.4	-2.7	0.1
	WW-NP	3533.5	2761.4	3284.6	2304.3	-772.1	-248.9	-1229.2	-21.9	-7.0	-34.8
YOY	CW-P	24100.5	24223.8	23882.2	24806.5	123.3	-218.3	706	0.5	-0.9	2.9
	CW-NP	27076.2	26793.9	26612.2	27580.8	-282.3	-464	504.6	-1.0	-1.7	1.9
	WW-NP	3424.4	2803.1	3210.2	2405.4	-621.3	-214.2	-1019	-18.1	-6.3	-29.8
Pooled: Adult		65176.9	64680.1	64908.4	64607.5	-496.8	-268.5	-569.4	-0.8	-0.4	-0.9
Spawning		15977.4	15665.1	15626.3	15948.8	-312.3	-351.1	-28.6	-2.0	-2.2	-0.2
YOY		18200.4	17940.3	17901.5	18264.2	-260.1	-298.9	63.8	-1.4	-1.6	0.4
OverAll Sum		33118.2	32761.8	32812.1	32940.2	-356.4	-306.1	-178	-1.1	-0.9	-0.5

Table 10. The weighted suitable area (WSA) results for Little Turkey Lake habitat manipulations application of the HSM model using lake species, partitioned by sub-areas. Shown is the pre- and post-manipulation of the two areas where geotextile was placed, nearshore, offshore, net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Type	Group	Pre 1	Pre 2	Nearshore	Offshore	Post 1	Post 2	Net Change 1	Net Change 2	% 1	% 2
Adult	CLDW-P	18.5	71.6	5592.1	94070.2	0	0	-18.5	-71.6	-100	-100
	CW-NP	84	341.6	9897.1	81252.7	7.7	10.6	-76.3	-331	-90.8	-96.9
	WW-NP	24.2	284	3894.7	0	0	0	-24.2	-284	-100	-100
Spawning	CW-P	147.8	197.7	19962.1	3160.3	43.8	58.7	-104	-139	-70.4	-70.3
	CW-NP	177	384.2	20369.6	0	0	0	-177	-384.2	-100	-100
	WW-NP	23.4	225.6	3284.6	0	0	0	-23.4	-225.6	-100	-100
YOY	CW-P	63	155.3	14149.2	9733	0	0	-63	-155.3	-100	-100
	CW-NP	61.7	402.2	25674.4	937.8	0	0	-61.7	-402.2	-100	-100
	WW-NP	9.4	204.8	3210.2	0	0	0	-9.4	-204.8	-100	-100
Pooled:											
Adult		42.2	232.4	6461.3	58441	2.6	3.5	-39.6	-228.9	-93.8	-98.5
Spawning		116.1	269.2	14538.7	1053.4	14.6	19.6	-101.5	-2	-87.4	-92.7
YOY		44.7	254.1	14344.6	3557	0	0	-44.7	49.6 -254.1	-100	-100
OverAll Sum		67.7	251.9	11781.5	21017.1	5.7	7.7	-62	-244.2	-91.6	-96.9

Table 11. The weighted suitable area (WSA) results for Quinn Lake habitat manipulations application of the HSM model using lake species, partitioned by sub-areas. Shown is the pre- and post-manipulation of the three wood removal areas, nearshore, offshore, net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Type	Group	Pre 1	Pre 2	Pre 3	Nearshore	Offshore	Post 1	Post 2	Post 3	Net Change 1	Net Change 2	Net Change 3	% 1	% 2	% 3
Adult	CLDW-P	725.5	921.5	1534.9	11498	16325.3	985.2	1266.7	2347.2	259.7	345.2	812.3	35.8	37.5	52.9
	CW-NP	341.8	429.7	1596.5	3704.4	0	82.1	91.3	792.7	-259.7	-338.4	-803.8	-76.0	-78.8	-50.3
Spawning	CLDW-P	242.7	331.5	532	3935.4	0	329.6	455.2	812.7	86.9	123.7	280.7	35.8	37.3	52.8
	CW-NP	462.4	557	1663.4	5114.5	0	248.8	279.1	982.5	-213.6	-277.9	-680.9	-46.2	-49.9	-40.9
YOY	CLDW-P	484.1	631.4	1037.8	7731.7	7370.4	657.4	867.5	1586.5	173.3	236.1	548.7	35.8	37.4	52.9
	CW-NP	809.4	1006	1916.5	12309.8	0	1003.9	1258.8	2519.3	194.5	252.8	602.8	24.0	25.1	31.5
Pooled:															
Adult		533.6	675.6	1565.7	7601.2	8162.6	533.7	679	1569.9	0.1	3.4	4.2	0.0	0.5	0.3
Spawning		352.6	444.2	1097.7	4524.9	0	289.2	367.1	897.6	-63.4	-77.1	-200.1	-18.0	-17.4	-18.2
YOY		646.8	818.7	1477.2	10020.7	3685.2	830.7	1063.2	2052.9	183.9	244.5	575.7	28.4	29.9	39.0
OverAll Sum		511	646.2	1380.2	7382.3	3949.3	551.2	703.1	1506.8	40.2	56.9	126.6	7.9	8.8	9.2

Table 12. The weighted suitable area (WSA) results for Wishart Lake habitat manipulations application of the HSM model using lakes species. Shown is the pre- and post-manipulation (partial and full wood removal), net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Type	Group	Pre	Post- partial removal	Post- full removal	Net Change- partial	Net Change-full	% partial	% full
Adult	CLDW-P	53266.4	53725.1	54171.2	458.7	904.8	0.9	1.7
	CW-NP	16471	16608.2	16659.7	137.2	188.7	0.8	1.1
	WW-NP	12160.8	11243.4	10351.2	-917.4	-1809.6	-7.5	-14.9
Spawning	CLDW-P	53783.7	54621.2	55355	837.5	1571.3	1.6	2.9
	CW-NP	50439.2	50671.9	50825	232.7	385.8	0.5	0.8
	WW-NP	10139.4	9349.6	8587.1	-789.8	-1552.3	-7.8	-15.3
YOY	CLDW-P	53800.8	54565.8	55187.2	765	1386.4	1.4	2.6
	CW-NP	57130.1	57570.4	58085.3	440.3	955.2	0.8	1.7
	WW-NP	10290.3	9854.3	9320.5	-436	-969.8	-4.2	-9.4
Pooled:								
Adult		27299.4	27192.2	27060.7	-107.2	-238.7	-0.4	-0.9
Spawning		38120.8	38214.2	38255.7	93.4	134.9	0.2	0.3
YOY		40407.1	40663.5	40864.3	256.4	457.2	0.6	1.1
OverAll Sum		35275.7	35356.6	35393.6	80.9	117.9	0.2	0.3

Table 13. The weighted suitable area (WSA) results for Wishart Lake habitat manipulations application of the HSM model using tertiary watershed species. Shown is the pre- and post-manipulation (partial and full wood removal), net change, and percent change in WSA by life stage, fish groups and pooled groups. Groups were weighted equally in this analysis. CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Type	Group	Pre	Post- partial removal	Post- full removal	Net Change- partial	Net Change-full	% partial	% full
Adult	CLDW-NP	4681.9	4685.2	4688.5	3.3	6.6	0.1	0.1
	CLDW-P	4285.4	4322.2	4358	36.8	72.6	0.9	1.7
	CW-NP	46267.4	46014.4	45708.8	-253	-558.6	-0.5	-1.2
	CW-P	32607.6	32181.3	31703.1	-426.3	-904.5	-1.3	-2.8
	WW-NP	47076.7	46803.4	46437.1	-273.3	-639.6	-0.6	-1.4
	WW-P	21832.5	21326.8	20759.6	-505.7	-1072.9	-2.3	-4.9
Spawning	CLDW-NP	29227.4	29805.5	30265.6	578.1	1038.2	2.0	3.6
	CLDW-P	39667.7	40384.1	40992.1	716.4	1324.4	1.8	3.3
	CW-NP	26404.1	26684.5	26835.3	280.4	431.2	1.1	1.6
	CW-P	21169.3	21362.7	21572.2	193.4	402.9	0.9	1.9
	WW-NP	14637.5	14352.7	13998.3	-284.8	-639.2	-1.9	-4.4
	WW-P	14408.7	14115.4	13797.5	-293.3	-611.2	-2.0	-4.2
YOY	CLDW-NP	14816.6	14915.5	15010.1	98.9	193.5	0.7	1.3
	CLDW-P	38068.4	38575.4	38960	507	891.6	1.3	2.3
	CW-NP	63936.4	64018.8	64164.5	82.4	228.1	0.1	0.4
	CW-P	40775.2	40535.7	40184.4	-239.5	-590.8	-0.6	-1.5
	WW-NP	27989.2	27651	27302.7	-338.2	-686.5	-1.2	-2.5
	WW-P	37085.3	37017.6	36805.7	-67.7	-279.6	-0.2	-0.8
Pooled:								
Adult		26125.2	25888.9	25609.2	-236.3	-516	-0.9	-2.0
Spawning		24252.5	24450.8	24576.8	198.3	324.3	0.8	1.3
YOY		37111.8	37119	37071.2	7.2	-40.6	0.02	-0.11
OverAll Sum		29163.2	29152.9	29085.7	-10.3	-77.5	-0.04	-0.27

Table 14. Summary of the observed changes (%) in the WSA after partial removal of wood in the lakes. I= increase, D= decrease, CLDW= coldwater, CW= coolwater, WW= warmwater, P= piscivore, NP= non-piscivore

Species List	Life Stage	Group	Little Turkey	Wishart	Quinn
Lake	Adult	CLDW-P	I	I	I
		CW-NP	D	I	D
		WW-NP	D	D	-
	Spawning	CLDW-P	I	I	I
		CW-NP	D	I	D
		WW-NP	D	D	-
	YOY	CLDW-P	I	I	I
		CW-NP	D	I	I
		WW-NP	D	D	-
Tertiary Watershed	Adult	CLDW-NP	I	I	I
		CLDW-P	I	I	I
		CW-NP	D	D	D
		CW-P	D	D	D
		WW-NP	D	D	D
		WW-P	D	D	D
	Spawning	CLDW-NP	I	I	I
		CLDW-P	I	I	I
		CW-NP	I	I	D
		CW-P	I	I	I
		WW-NP	D	D	D
		WW-P	D	D	D
	YOY	CLDW-NP	I	I	I
		CLDW-P	I	I	I
		CW-NP	I	I	I
		CW-P	D	D	D
		WW-NP	D	D	D
		WW-P	D	D	D

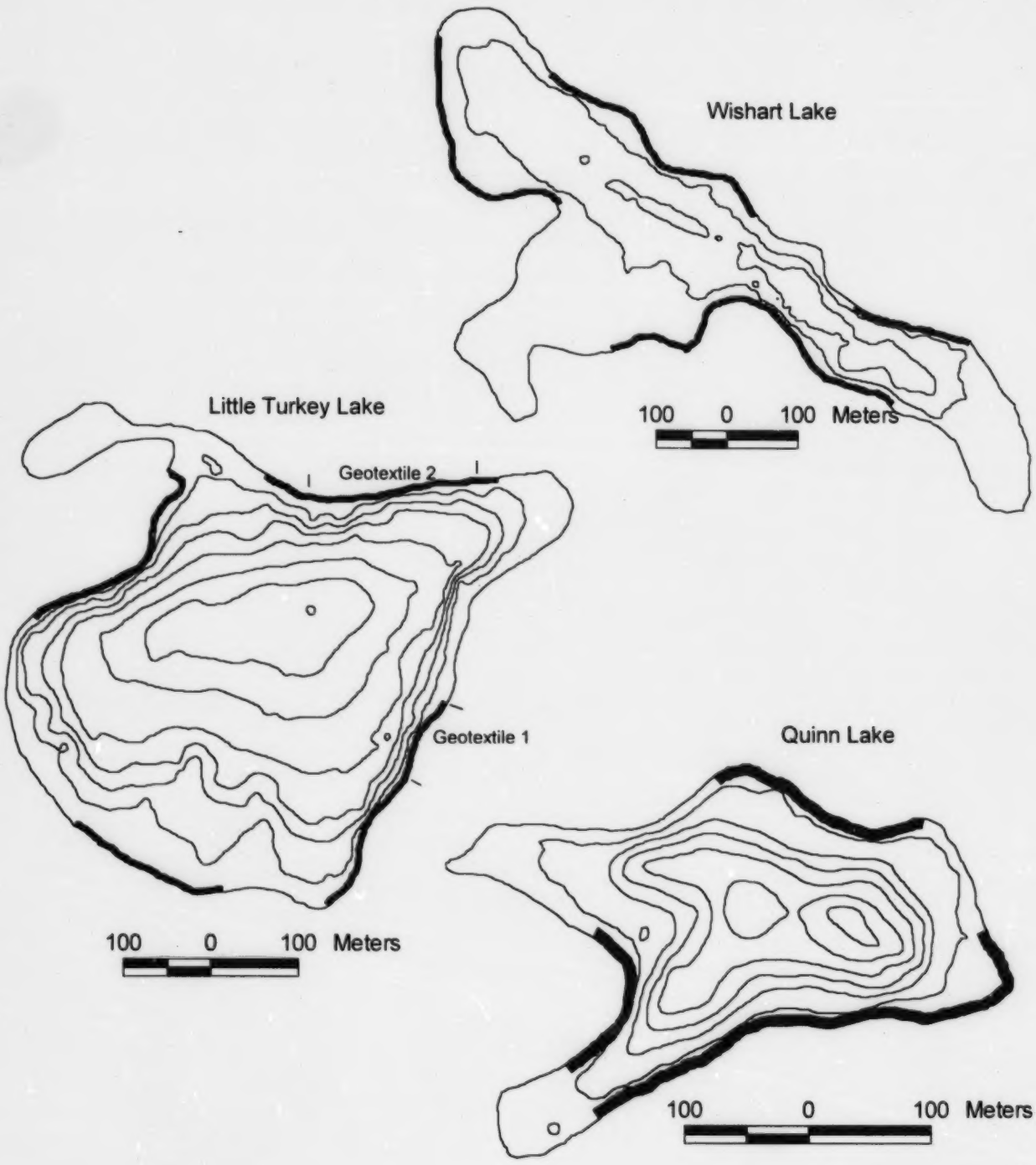

Figure 1. The striped areas around each lake indicate the approximate areas where CWM was removed. In Little Turkey Lake, shaded areas within the wood removal areas are the locations of the geotextile material. The approximate area of wood removal was 9726.36 m^2 in Wishart Lake, 5826.78 m^2 in Little Turkey and 5869.67 m^2 in Quinn Lake. Geotextile was placed over an area approximately 900 m^2 in Little Turkey Lake.

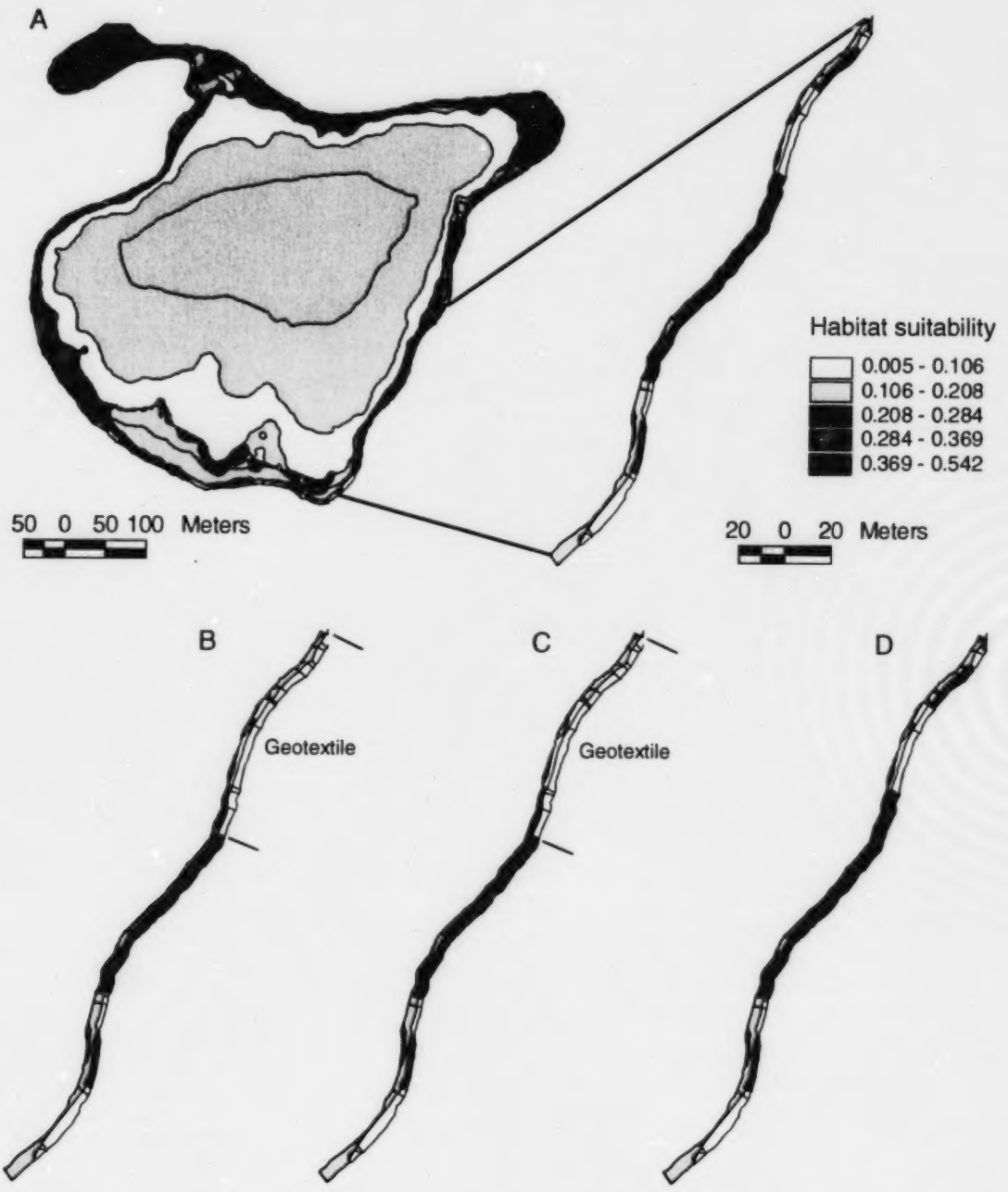

Figure 2. Habitat suitabilities of composite lake species for Little Turkey Lake pre- and post-manipulation. A) Whole lake and pre-manipulated area (min=0.055, max=0.47); B) Post-manipulation addition of geotextile (artificial substrate) (min=0.01, max=0.47); C) Post-manipulation wood removal and geotextile addition (min=0.02, max=0.47); D) Post-manipulation wood removal only (min=0.07, max=0.5).[Ideal habitat suitabilities equal 1].

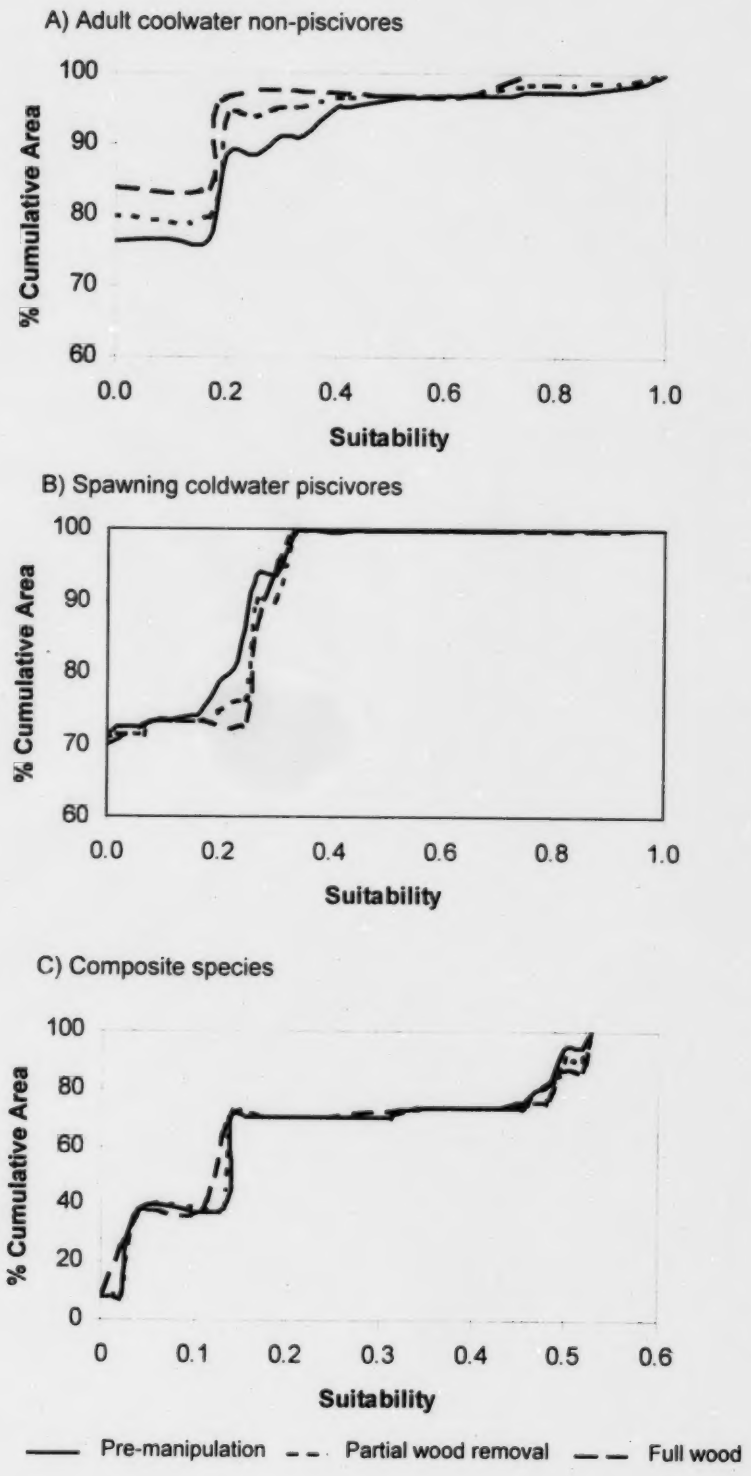

Figure 3. Cumulative area versus Quinn Lake habitat suitabilities for A) adult coolwater non-piscivores, B) spawning coldwater piscivores, and C) composite species .